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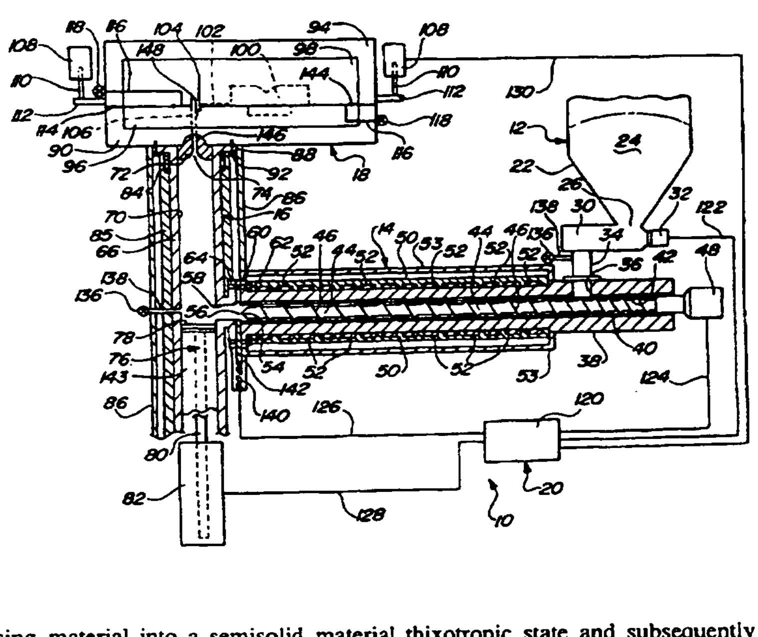

(57) Abstract

An apparatus for processing material into a semisolid material thixotropic state and subsequently die casting the materials. The apparatus includes a shearing mechanism (14) and a shot sleeve (16) and also includes a barrel (38) which is adapted to receive either solid or liquid material thereinto at one end. As the material is passed through the barrel (38) it is subjected to shearing and heating or cooling to bring the material to a temperature which permits the presence of both liquid and solid particles therein. The shearing action promotes the formation of non-dendritic spherical particles and, accordingly, a semisolid thixotropic slurry is formed. From the shearing mechanism (14) the slurry is metered into a shot sleeve (16) and once a single shot or charge of the slurry is received therein, a ram (76) is advanced to force the slurry into a casting die cavity (100) where it solidifies in the form of the desired article.

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APPARATUS FOR PROCESSING SEMISOLID THIXOTROPIC METALLIC SLURRIES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus for producing a thixotropic state in metallic materials in order to die cast, mold and forge these materials into articles of manufacture.

2. Description of the Prior Art

Metal compositions having dendritic structures at ambient temperatures conventionally have been melted and then subjected to high pressure die casting procedures. These conventional die casting procedures are limited in that they exhibit porosity, melt loss, contamination, excessive scrap, high energy consumption, lengthy duty cycles, limited die life, and restricted die configurations. Furthermore, conventional processing promotes formation of a variety of microstructural defects, such as porosity, that require subsequent, secondary processing of the articles and also result in use of conservative engineering designs with respect to mechanical properties.

Processes are known for forming these metal compositions such that their microstructures consist of rounded or spherical, degenerate dendritic particles surrounded by a continuous liquid phase as opposed to a classical equilibrium microstructure of dendrites surrounded by a continuous liquid phase. These new structures exhibit non-Newtonian viscosity, an inverse relationship between viscosity and rate of shear, and are thus known as thixotropic materials.

One process requires heating of the metal composition or alloy to a temperature above its liquidus temperature and then subjecting the liquid metal alloy to a high shear rate as it is cooled into the region of two phase equilibria. A result of the agitation during cooling causes the initially solidified phases of the alloy to form as rounded primary particles (as opposed to interconnected dendritic particles). As a result, the primary solids are comprised of discrete, degenerate dendritic spherules surrounded by a matrix of an unsolidified portion of the liquid alloy.

Another method for forming thixotropic materials involves heating the metal alloy to a temperature at which most but not all of the metal is in a liquid state. The alloy is then fed into a temperature controlled zone where it is cooled to a constant temperature and agitated. Th agitation of the material during cooling converts any remaining solid particles into degenerat dendritic spherules. In this method, it is preferred that when initiating agitation, the semisolid m tal contain less solid than liquid.

An injection molding technique using metal alloys delivered in an "as cast" state has also been seen. With this technique, the feed material is fed into a reciprocating screw injection unit where it is ext mally heated and mechanically sheared by the action of a revolving screw. As the material is agitated by the screw, it is moved forward within the barrel. The combination of partial

m lting and simultaneous shearing produc s a slurry of a liquid containing discrete d g nerate dendritic spherical particl s, or in other words, a semisolid state exhibiting thixotropic properties. The semisolid material thixotropic slurry is delivered by the screw to an accumulation zone in the barrel which is locat d between the extruder nozzle and the screw tip. As the slurry is delivered into this accumulation zone, the screw is simultaneously withdrawn in a direction away from the unit's nozzle. This limits the pressure build-up between the nozzle and the screw tip. Once an appropriate amount of slurry for the production of the article to be produced has accumulated in the accumulation zone, the screw is rapidly and automatically driven forward injecting the semisolid material thixotropic slurry into the die cavity and forming the desired solid article out of the semisolid thixotropic slurry.

While an apparatus has been seen for injection molding these two phase semisolid material thixotropic slurries over a wide range of temperatures, the application of these materials to die casting and forging processes has not yet been detailed. One exception to the above are the processes limited to very high solid fractions, greater than 50% by volume, which involve separate processes for (1) preforming a billet with thixotropic properties, (2) sizing the billet, (3) reheating the billet to the critical temperature of its formation, (4) handling and (5) placing it in a device for final forming.

In view of the foregoing, it should be apparent that there still exists a need in the art for an apparatus capable of exploiting the benefits of producing semisolid material thixotropic slurry for use in die casting and forging processes.

It is therefore a primary object of this invention to fulfil that need by providing a system for processing semisolid material thixotropic slurry which is directly adaptable to die casting or forging apparatuses.

An object of this invention is to allow for the use of semisolid material thixotropic slurry in an apparatus which is more recognizable to end users, such as metal part manufacturing companies.

Another object of this invention is to provide an apparatus which is of a conventional size as compared with previous die casting machines.

A further object of this invention is to provide an apparatus having an increased material capacity over prior thixotropic injection molding machines.

Still another object of this invention is to provide an apparatus which eliminates the need for maintaining an inventory of pre-sized billets for die casting purposes. In this regard a related feature is that no longer will such pre-sized billets have to be rapidly and uniformly heated from a storage temperature to a nominal formation temperature and then physically transferred to a shot sl ve. Accordingly, the present inv ntion also eliminates the probl ms of typical die casting machines associat d with shape r t ntion of the preh ated billets prior to loading of the billet into the shot sleeve.

Anoth r obj ct of this invention is to provid an apparatus which eliminates the ne d for physical handling or preheating of a solid charge before introduction to the shot sleeve of the die casting machine.

SUMMARY OF THE INVENTION

Briefly described, these and other objects are accomplished according to the present invention by providing a semisolid material thixotropic slurry processing apparatus having an extruder coupled to a shot sleeve further coupled to a casting die. The extruder barrel includes an inlet located toward one end of the barrel and an outlet located at the opposing end of the barrel. The inlet is adapted to receive the material into the barrel from a solid particulate or pelletized metal feeder, or liquid metal source, at a first temperature. The outlet is adapted to transfer the mat rial out of the barrel at a second temperature. By establishing an appropriate thermal gradient, heating elements about the barrel serve to heat the material into the two phase region or alternately to cool the material to the second temperature. This second temperature is between the solidus and liquidus temperatures of the material wherein the material will be in a semisolid state, i.e., there is a thermodynamic equilibrium between the primary alpha solid phase and the liquid phase.

A non-reciprocating extruder screw is located within the barrel and is rotated to move the material through the barrel, from the inlet to the outlet, in manner which subjects the material to a mechanical shearing action as its temperature is being adjusted to the second temperature. The combination of these actions produces the thixotropic structure consisting of rounded degen rate dendrites surrounded by a liquid phase within the material.

A shot sleeve, consisting of a second heated barrel or sleeve with an inlet passageway and an outlet nozzle, receives the material from the outlet of the extruder barrel. The outlet nozzle of the shot sleeve includes a temperature control mechanism, although additional bands around the shot sleeve itself may prove beneficial for large capacity shot sleeves.

Mounted for axial movement within the shot sleeve is a hydraulically actuated ram that can be preferably accelerated at velocities of up to 200 inches per second. In order to meter a predetermined amount of the semisolid material thixotropic slurry into the shot sleeve from the extruder, a controller is coupled to the feeder and the drive mechanism which rotates the extruder screw. When an amount of material corresponding with the amount capable of being mold d or die cast during one shot cycling of the ram has been received within the shot sleeve, screw rotation is interrupted and the controller initiates actuation of the ram toward the outlet nozzle.

Generally simultaneously therewith, the controller also closes a valve which seals the inlet into the shot sleeve during movement of the ram. The valve prevents backflow of the material into the extruder during forward movement of the ram. Additionally, the valve prevents the inflow of material into the shot sleeve g nerally behind th ram when the ram is locat d b tween the inlet and the outlet nozzle of the shot sleeve. The valve may be sel cted from a variety of slide gate

valv s or utilizing a trailing shroud or skirt on the ram, the form r of which is known in the industry.

The invention also includ s a gas and evacuation source which provid s a protective atmosphere for the material whil in the apparatus. The protective atmosphere is non-reactive with the material and may be s l ct d from a variety of non-reactive gases with Argon preferred for processing Mg alloys. From the outlet nozzle, the material is forced in a die cavity defined by a two part mold including a stationary part and movable part. In one alternative embodiment of the invention, the shot sleeve is inclined relative to the casting die with the nozzle outlet below the inlet. In another embodiment, multiple extruders are used with a single shot sleeve to increase the charge capacity of the shot sleeve.

Additional benefits and advantages of the present invention will become apparent to those skilled in the art to which the present invention relates from the subsequent description of the preferred embodiment and the appended claims, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is schematic illustration of one embodiment of an apparatus for processing thixotropic materials according to the principles of the present invention;

FIG. 2 is schematic illustration of a shot sleeve and casting die according to the principles of the present invention illustrating the relative angles therebetween;

FIG. 3 is a schematic illustration of the apparatus according to the present invention and being utilized with forging dies;

FIG. 4 is a schematic illustration of another embodiment of the present invention showing multiple extruders being used with one shot sleeve;

FIG. 5 is a schematic illustration of another embodiment of the present invention showing the extruder angled with respect to the shot sleeve; and

FIG. 6 is a schematic illustration of an electromagnetic pump associated with the barrel.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention discloses an apparatus for processing materials into a thixotropic state and molding the material to form molded, die cast, or forged articles. Unlike typical die casting and forging machines, the present invention is adapted to use a room temperature feed stock of a metal or metal alloy. This eliminates the use of a melting furnaces in the die casting forging process along with the limitations associated therewith. It is also capable of accepting liquid feed stock and thus is immediately compatible with existing die cast foundry operations that might not b quipped to immediately adopt th use of solid feed stock in a chipped or pelletized form. The apparatus of the present inv ntion transforms the room temperature feed stock or liquid f ed into a semisolid, thixotropic slurry which is fed as it is form d directly into the shot sleeve from

which the metal is die cast molded, or forged.

As with parts form d by the injection molding of thixotropic materials mentioned above, it is anticipated that articles formed in the apparatus of the pr s nt invention will exhibit a considerably lower porosity than conv ntionally di cast articles. It is well known that by d creasing porosity the strength and ductility of the part or article can be increased. Obviously, any reduction in casting defects as well as any decrease in porosity is seen as being desirable.

Referring now to FIG. 1, an apparatus embodying the principles of the present invention is schematically illustrated therein and designated at 10. The die casting apparatus 10 of the present invention will be seen as incorporating some features which have analogous featur s in conventional die casting equipment. This is actually beneficial since it allows individuals already familiar with die casting equipment to quickly become acclimated to the processing of thixotropic materials with the present invention. Furthermore, it provides the opportunity for die casting machines to be cost efficiently retro-fitted to enable the processing of materials into a thixotropic state. Principally, the apparatus 10 of the present invention includes a feeder 12, an extruder 14, a shot cylinder 16, a molding station 18 and a system controller 20 which coordinates the various operations of the other elements.

The feeder 12 is a gravity feeder and includes a feed hopper 22 in which the feed stock 24 is kept at room temperature. Preferably the feed stock 24 is provided in either a pellet or chipped form, with the chip form being the most preferred, and is of a size within the range of 4-20 mesh. One group of metal alloys which are suitable for use in the apparatus 10 of the present invention include the magnesium alloys. However, the present invention should not be interpreted as being so limited since it is believed that any metal or metal alloy which is capable of being die cast can be processed into a thixotropic state and will find utility with the present invention, in particular Al and Zinc based alloys.

At the bottom of the feed hopper 22, the feed stock 24 is gravitationally discharged through an outlet orifice 26 into a volumetric feed cylinder 30. A feed auger (not shown) is located within the cylinder 30 and is rotationally driven by a suitable drive mechanism 32, such as an electric motor. Rotation of the auger within the feed cylinder 30 advances the feed stock 24 at a predetermined rate for delivery to the extruder 14 through a connecting conduit 34. Depending on whether the material 24 is in a solid or molten/liquid form, alternative delivery systems can be used where appropriate.

Where molten material 24 is being fed into the extruder barrel 38, feeding can be by a robotic ladeling mechanism, by hand or by a pumping of the molten material, such as by electromagnetic or inductive pumping. The advantage of the above is that, when retro-fitting the pres nt invention to xisting foundry equipment, no new material handling concerns are raised.

As an alternative to the extrud r 14 and as schematically shown in FIG. 6, electromagn tic or inductive pumping can being employed, entirely obviating the need for an extruder.

This is achieved by incorporating an lectromagnetic device or pump 39 of common design around a conv yance barrel 38 that connects to and deliv rs th slurry to the sh t sle ve 16. Devices of this kind are used by properly orienting and operating the electromagnetic fi ld produced by the pump 39 to pump molten metals from one vessel to another e.g. from a feeder 30 of molt n metal to the shot sleeve 16. The electromagnetic field fulfills a further purpose by stirring and/or shearing the fluid which, if its temperature is allowed to drop into the two phase semisolid range, can be adjusted to alter the dendritic solid to nodular/rounded particles ratio imparting the thixotropic state to the slurry. Mixing and stirring during this pumping/transfer process can be further augmented by incorporation of stationary turbulators or elements 41 on the inner diamet r of the transfer barrel 38. Such turbulators 41 enhance heat transfer from and to the material. A preferred embodiment would come from a class of spiral vanes, alternately changing the rotation of the moving fluid from clockwise to counter-clockwise as it progresses toward the shot sleeve. This action will further benefit the establishment of the desired temperature in the semisolid material thixotropic slurry since the fluid will, in most instances, be introduced to the mechanism at or above it's melting point.

When an extruder is utilized, the conduit 34 is coupled to a feed throat 36 in a barrel 38 of the extruder 14. The extruder barrel 38 defines a cylindrical passageway 40 which is lined with a sleeve 42 that increase the wear resistance of the barrel 38. Suitable barrel 38 materials may include alloy 718, alloy 2888 and H21 tool steel. Suitable sleeve 42 materials depend on the particular material being processed. For example, with magnesium these include cobalt-chromium alloys.

Located with the passageway 40 of the barrel 38 is a rotatable extruder screw 44. A helical vane 46 extends about the screw 44 and propels the feed stock 24 through the passageway 40 during rotation of the screw 44. Like the auger located within the feed cylinder 30, the extruder screw 44 is rotated by an appropriate drive mechanism 48, such as an electric motor. The extruder screw 44 terminates in a tip 54 which is adjacent to the exit opening 56 of the passageway 40. This opening 56 in turn leads to the feed throat 58 of the shot cylinder 16 which is further described below.

Along its forward length, it can be seen that the barrel 38 is encircled by a temperature control apparatus which causes the feed stock 24 to be heated or cooled, depending on the temperature and state at which the material 24 is introduced into the barrel 38, due to conduction through the barrel 38. The temperature control apparatus can be provided with various types of heating or cooling elements in order to achieve this intended purpose. As illustrated, heating/cooling 52 elements are representatively shown in FIG. 1 and consist of resistance band h at rs or cooling coils. An induction heating coil may be used in an alternate configuration to provide more rapid heat up of the barrel 38. The band resistance heaters 52 are pref rr d in that they are more stable in operation, less expensive to obtain and operate and do not unduly limit

h ating rat s or capacity, including cycle times.

As seen in FIG. 1, the rear or aft nd of the barrel 38 need not be provided with heaters. While heaters are s en in the figur s, th actual number can b more or l ss dep nding on the specific application.

Tightly wrapped over the temperature control elements 52 is an insulative layer or blanket 50 which facilitates heat transfer through the barrel 38 to or from the melt. To further maximize heat transfer in through the cylindrical portion 66, as well as to minimize heat/gain losses to the surroundings, a housing 86 can be disposed exteriorly about the length of the shot sleeve 16, but is generally not believed to be necessary. Additionally, the extruder 14 is rigidly mounted with respect to the shot cylinder 16. To facilitate this mounting, the barrel 38 is provided with a radial flange 60 adjacent to the exit opening 56. The flange 60 is secured by threaded fasteners 62 or other conventional fastening methods to a corresponding flange 64 adjacent the feed throat 58 of the shot sleeve 16.

The shot sleeve 16 includes cylindrical portion 66 which defines a passageway 70 therethrough. Suitable materials for the cylindrical portion 66 respectively include _typical shot sleeve materials of construction (tool steels). The cylindrical portion 66 might also include a sleeve liner (not shown) constructed from cobalt-chromium alloys, silicon-nitride, and other materials found to give a longer useful life to the liner.

The feed throat 58 is generally located toward one end of the shot sleeve 16 and defines a passageway through both the barrel 66 and the liner 68. Generally located at the opposing end of the shot sleeve 16 is an outlet nozzle 72. The nozzle defines an outlet passageway 74 leading to the molding station 18.

Located within the passageway 70 of the shot sleeve is an axially movable ram 76 which includes a head 78 to which is attached a rod 80. Axial movement of the ram 76 is induced by an appropriate actuator 82, such as a hydraulic actuator, in which the rod 80 terminates. The head 78 of the ram 76 can be advanced and retracted a distance within the passageway 70 such that, when in its retracted position, the feed throat 58 of the shot sleeve 16 is located between the head 78 and the outlet nozzle 72. In its extended or advance position, the head 78 of the ram 76 is located between the feed throat 58 and the outlet nozzle 72.

Positioned about the cylinder 66 and along substantially its entire length is a blanket 85 of insulative material. The blanket 85 maintains the material accumulated within the passageway 70 at a temperature generally corresponding to the temperature at which the material is discharged from the extruder 14. If desired, but not believed necessary, a series of heating elements, similar to the band resistance heaters 52 discussed previously, can be positioned about the cylinder 66. Such h aters may prove useful with large capacity shot sleeves in th ev nt the feed rate from the extruder 14 to the shot sleeve 16 is relatively long in comparison to conventional die casting techniques.

Temperature control bands 84 are also placed about the outlet nozzle to control its temperature and permit formation of a solid plug as discuss d below. The plug generally prevents drooling, oxyg n nt ring into the shot sl v 16, and also facilitat s vacuation of the di of th molding station 18 when desired.

To secure the shot sleeve 16 to the molding station 18, the barrel 66 is provided with a radial flange 88 adjacent to its nozzle end. The flange 88 is secured to a stationary platen 90 of the molding station 18 by threaded fasteners 92 or another suitable fastening method. It may also have a flange and be held in position by a pair of hydraulic pulley cylinders that prevent unlatching during a shot cycle.

While not believed required, a casing 86 could be placed about the entire shot sleeve 16.

The stationary plate 90 cooperates with a movable platen 94 and each has respectively attached thereto a stationary mold half 96 and a moveable mold half 98. Mold halves 96 and 98 include surfaces which combine to define a mold cavity 100 in the shape of the article being molded. Connecting the mold cavity 100 to the outlet passageway 74 of the nozzle are a runner 102, gate 104 and sprue 106.

Translational movement of the movable platen 94 and movable mold half 98 is caused by one or more actuators 108. The actuators 108 include movable rods 110, one end of which is fixedly secured to the movable platen 94 by a brace 112. Actuation of the actuators 108 caus s the rods 110 to be advanced out of the actuators 108 and this in turn, through the brace 112, forces the movable platen 94 into surface-to-surface engagement with the stationary platen 90 as is generally indicated by the mold parting line 114.

To provide an evacuated atmosphere within the mold cavity 100 during molding of the part, evacuation occurs through a pair of lines 116 connected to evacuation source 118. Line 116 and the evacuation source 118 can be provided with respect to either mold half 96. or 98 and one ne d not particularly be associated with either the stationary mold half 96 or the movable mold half 98.

As mentioned previously, the system controller 20 coordinates operation of the various elements of the apparatus 10 of the present invention. The system controller 20 preferably includes a programmable microprocessing unit (MPU) 120 which is connected through line 122 to the drive mechanism 32 of the feeder 12, through line 124 to the drive mechanism 48 of the extruder 14, through line 126 to an actuator 140 of a slide gate 142, through line 128 to the actuator 82 of th shot sleeve 16 and through line 130 to the actuators 108 of the mold 18. Additionally, the system controller 20 is coupled to the gas and evacuation sources 118 and 118′and may be coupled to the induction coil heaters 50 and the band resistant heaters 52.

During operation of the apparatus 10, the heaters 50 and 52 are turned on to thoroughly heat the barr l 38 of the extruder 14 to the proper t mperature or t mperatures along its length. Th system controller 20 then actuates the drive mechanism 32 of the feeder 12 causing the auger within the feed cylinder 30 to rotate. This auger prop ls the room temperature fe d stock 24 into

the transfer conduit 34 wh re a protectiv atm sph re is maintained by an inert gas atmosph re or vacuation source 132 connected to the transf r conduit 34 by supply lin 134. The source 132 and line 134 are used to introduce an inert gas, such as Argon, being provided into the environment within the extruder and shot sle ve as further d scribed below.

From the transfer conduit 34, the feed stock 24 passes through the feed throat 36 in the extruder barrel 38 where it comes into contact with the rotating extruder screw 44 which is being rotated by the drive mechanism 48 that was actuated through line 124 by the system controller 20. Within the passageway 42 of the extruder 14, the feed stock 24 is propelled therealong by the vane 46 of the screw 44. As the feed stock 24 passes through passageway 42, the heat generated by the heaters 52 raises the temperature of the feed stock 24 to a temperature between its solidus temperature and its liquidus temperature. Within this temperature range, the material of the f d stock 24 forms a semisolid state comprised of the liquid phase of some of its constituents in which is disposed a solid phase of other of its constituents. The rotation of the screw 44 and vanes 46 induces shear into the semisolid material at a rate sufficient to prevent dendritic growth with resp ct to the solid particles in the semisolid material creating a thixotropic slurry. Depending on the particular application and article being molded with the molding station 18, the temperature induced in the slurry, as well as the shearing of the screw 44, will preferably provide for fraction solids (f_s) within the range of 0.05 f_s to .66 f_s in the semisolid material.

If desired, the feed stock 24 can be provided into the barrel 38 of the extruder 14 aft r having already been initially heated so that the material is in a semisolid state or in a fully molten (all liquid) superheated state. In this case, the action of the screw 44 propels the material and the vane 46 induce shear to inhibit dendritic growth resulting in the thixotropic slurry. If the material 24 is provided in a fully liquid state, the temperature control mechanism is adjusted so as to cool the material 24 from an all liquid state to a mixture of solid and liquid.

As mentioned above, the thixotropic slurry is received into the shot sleeve 16 through the feed throat 58. While in the shot sleeve 16 the temperature of the slurry remains within ± 5°C of the temperature of the slurry exiting the extruder 14.

The slurry is continuously fed into the passageway 70 by the screw 44 until an amount of slurry equivalent to that necessary for completely filling the die cavity 100 in a single shot is contained therein. The system controller 20, by varying the drive inputs from the drive mechanisms 32 (in the feeder 12) and 48 (in the extruder 14) causes the proper amount of slurry to be meter d into the shot sleeve 16. As mentioned above, an inert atmosphere is maintained within the passageways 70 and 40 of the shot sleeve 16 and extruder 14. An inert gas, such as Argon, is provided from a source 136′ which communicate with the passageway 70 through lines 138′.

Depending on th ratio of liquids to solids in the semisolid slurry, it is recognized that the molten material nt ring the shot sleeve 16 will have a relatively high viscosity as the sh ar stress is reduced. The charge will accumulate in a manner that disposes most of its mass on the bottom

surface of the shot sl ve 16.

Once the proper amount of slurry has been accumulat d within th passageway 70 of the shot sl ve 16, for th article t be mold d, along with a nominal amount for a residual cushion after die filling, the system controller 20 causes the actuator 82 to advance the ram 76. Generally simultaneously with the advancement of the ram 76 and preferably slightly therebefore, the system controller 20 also slows or stops rotation of the screw 44 and causes the actuator 140 to advance the slide gate 142 so as to obstruct the exit opening 56 of the extruder 14. Closing of the slide gate 142 serves two purposes including preventing the backflow of the slurry into the extruder 14 during advancement of the ram 76 and preventing the slurry from being dispensed into the shot sleeve 16 behind the advancing ram 76. As an alternative to the slide gate 142, the ram 76 can be provided with a ram skirt or shroud 143 that will occlude the inlet throat 58. The shroud 143 extends rearward from the head 78 of the ram 76 a distance which is greater than the stroke of the ram 76. Accordingly, as the ram 76 is advanced, the shroud 143 occludes the inlet throat 58 and continues to do so until the ram 76 is again fully retracted. In this way, material is not inadvertently deposited rearward of the head of the ram 76.

The ram 76 is activated utilizing the controller 20 to initially accelerate to a velocity of approximately 1 to 5 inches/second. This compacts the shot charge in the forward end of the sleeve 16 adjacent to the nozzle 72. The relatively slow speed permits compaction and squeezes or forces excess argon or another protective gas out of the charge space by leakage through the annular space between the ram 76 and shot sleeve 16. Immediately upon compacting the charg to a predetermined ram 76 position, the velocity of the ram 76 is rapidly increased raising th pressure to a level sufficient to blow a plug 146 from the nozzle passageway 74 into a sprue cavity 148 designed to catch it. As the instantaneous pressure drops, the velocity increases to a programmed level, typically in the range of 40 to 120 inches/second in the case of magnesium alloys. Upon the ram reaching the position corresponding to a full die, the pressure again begins to rise at which time the controller 20, drops the pressure to a level as low as 10% of the steady state value achieved, and motion of the ram 76 is then arrested to reduce the pressure to zero or a negative value. The controller 20 permits a wide choice of velocity profiles in which the pressure/velocity relationship can be varied by position during the shot cycle, which may typically be as short as 40 milliseconds or up to 200 milliseconds, of the ram 76, depending on the shot size.

Once the ram 76 stops advancing, the material located within the outlet passageway 74 solidifies within the passageway forming a solid plug which seals off the passageway 74. This prevents the drooling of material from the passageway 74 during opening of the mold halves 96 and 98 and removal of the molded article. This opening of the mold is also synchronized by the system controll r 20 which causes th actuators 108 to retract th movable plat n 94 and mold 98 away from th stationary platen 90 and mold 96. This action also s rves to break the sprue from the residual plug. Once opened, a transf r mechanism (not shown) removes the molded article from

the movable mold 98 and the system controller 20 then causes the actuators 108 to re-close the mold for the next op rating cycle.

In the event vacuum enhanced molding is desired, then to ensure complete sealing of the movabl mold 98 with the stationary mold 96, a seal is formed by an appropriate s aling mechanism 144 which is retained with one of the mold halves 96 or 98. One such appropriate sealing mechanism would be an O-ring variety.

Once closed and sealed, the mold cavity is evacuated by one or both evacuation sources 118 generally creating a vacuum within the mold cavity 100. The plug 146 mentioned above, cooperates with the evacuation source 118 to ensure that complete evacuation occurs from the outlet nozzle 72 through the sprue 106, gate 104 and runner 102, as well as the mold cavity 100.

During subsequent molding of the next article, advancement of the ram 76 will cause the plug 146 to be forced out of the outlet passageway 74 and into the sprue 106. The sprue 106 extends beyond the gate 104 and is provided with a recess 148 which is intended to receive the solidified plug 146 without interfering with the flowing of the slurry through the gate 104 and runner 102 into the mold cavity 100. After molding, the plug 146 is retained with the solidified material of the gate 104 and runner 102 and will be trimmed from the article during the subsequent trimming step.

In an alternative embodiment of the present invention, the shot sleeve 16 is inclined with respect to the mold 18 as seen in FIG. 2. The shot sleeve 16 is inclined at an angle A such that the nozzle 72 is positioned downward from the inlet throat 58. Preferably, the downward inclination of the shot sleeve 16 is from 5° to 45° out of horizontal and more preferable from 15° to 30°. This promotes movement of the slurry away from the inlet throat 58 from the extruder 14 and into the shot sleeve 16. Because of the increased viscosity of the slurry and the absence of increased shear in the shot sleeve 16, minimal amounts of gas from the source 136 becomes entrapped in the slurry which is being deposited into the shot sleeve 16. Additionally, the inclination of the shot sleeve 16 causes the full charge of slurry volume to be located at the nozzle 72 end of the shot sleeve 16 before actuation of the ram 76. This further prevents the slurry charge from being forced out of the feed throat 58 and into the extruder 14. Alternatively, the barrel 38 of the extruder 14 can be inclined relative to the shot sleeve 16 so that the barrel 38 feed throat 36 is elevated relative to its outlet opening 56.

When the present invention is utilized with forging dies, as seen in FIG. 3, the shot sleeve 16 is configured to directly deposit the thixotropic slurry into one die 96′ of a forging press 18′. When the proper volume of the slurry has been deposited in the forging die 96′, the system controller 20 actuates an actuator, generally designated at 108′, moves a movable platen 98′causing the desired articl to be forged from the semisolid material thixotropic slurry.

Another mbodiment of the present invention is seen in FIG. 4. In this mbodiment, two or more extruders 14 are connected to a common large capacity shot sleeve 16. Accordingly,

larger articles can thus be molded without being limited by the capacity of a single extrud r 14. In substantially all other respects, this embodiment operates the same as the first described mbodiment.

Additi nally, as schematically illustrated in FIG. 5, the extruder can be canted at an angl B, less than 90°, relative to the axis of the shot sleeve 16 so that material 24 is directed into the shot sleeve 16 generally in the direction of the nozzle 72. This can be done with or without inclining the barrel 38 relative to the shot sleeve 16.

While the above description constitutes the preferred embodiment of the present invention, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the proper scope and fair meaning of the accompanying claims.

CLAIMS

1. An apparatus for processing mat rial into a thixotropic stat , said apparatus comprising:

an extruder barrel having an inlet and an outlet, said inlet located toward one end of said barrel and adapted to receive said material into said barrel at a first temperature, said outlet adapted to transfer said material out of said barrel;

feeder means for delivering said material into said barrel through said inlet;

temperature means for controlling temperature of said material to a second temperature where said material is in a semisolid state, said second temperature being between a solidus and liquidus temperature of said material;

shearing means for inducing a shearing action into said material in a manner to inhibit dendritic growth and induce formation of spherical degenerate dendrites within said material and maintain said material in a semisolid thixotropic state, said shearing means also moving said material through said barrel from said inlet to said outlet;

a shot sleeve having an inlet and an outlet nozzle, said inlet located generally at one end of said shot sleeve and said outlet nozzle located generally at an opposing end f said shot sleeve, said inlet of said shot sleeve positioned to receive said mat rial from said outlet of said barrel;

a ram mounted for axial movement within said shot sleeve between fore and aft positions, actuation means for causing axial movement of said ram in said shot sleeve between said fore and aft positions thereby ejecting said material out of said shot sleeve through said outlet nozzle;

control means for metering a predetermined amount of said material into said shot sleeve, said predetermined amount corresponding with an amount capable of being discharged out of said outlet nozzle during one cycling of said ram;

valve means for closing and sealing said inlet of said shot sleeve during movement of said ram preventing backflow of said material through said inlet during forward movement of said ram; and

environment means for providing a protective atmosphere for said material while in said apparatus, said protective atmosphere being non-reactive with said material.

2. An apparatus as set forth in Claim 1 wherein said barrel is adapted to receive said materials in a solid state.

3. An apparatus as set forth in Claim 1 wherein said barrel is adapted to receive said materials in a liquid state.

4. An apparatus as set forth in Claim 1 wh rein said barrel is adapted to receive said materials in a semisolid state.

5. An apparatus as set forth in Claim 1 wherein said second temperature is great r than said first temperature.

6. An apparatus as set forth in Claim 1 wherein said shearing means includes a rotatable screw and drive mechanism for rotating said screw such that material is moved from said inlet to said outlet of said barrel.

7. An apparatus as set forth in Claim 1 wherein said shearing means includes an electromagnetic pump such that material is moved through said barrel.

8. An apparatus as set forth in Claim 7 wherein said barrel includes elements therein creating a tortuous passage enhancing shearing.

9. An apparatus as set forth in Claim 1 wherein said ram includes a head, when said ram is in said aft position, said inlet of said shot sleeve being located between said head and said outlet nozzle.

10. An apparatus as set forth in Claim 1 wherein said ram includes a head, when said ram is in said fore position said head being located between said inlet of said shot sleeve and said outlet nozzle.

11. An apparatus as set forth in Claim 1 wherein said control means includes a microprocessing unit (MPU), said MPU coordinating the rate at which said shearing means moves said material through said outlet.

12. An apparatus as set forth in Claim 11 wherein said control means is coupled to and coordinates said feeder means, said shearing means, said barrel temperature means, said actuation means, said valve means and said environment means to operate said apparatus.

13. An apparatus as set forth in Claim 1 wherein said valve means includes a slide gate, said slide gate covering said inlet of said shot sleeve when said ram is in said fore position.

14. An apparatus as set forth in Claim 1 wherein said valv m ans includes a shroud formed on said ram, said shroud extending rearward relative to said ram and covering said inlet of

said shot sleeve when said ram is in said fore position.

15. An apparatus as set forth in Claim 1 wherein said protective atmosph re includes an inert gas th reby preventing oxidation of said mat rial within said apparatus.

16. An apparatus as set forth in Claim 1 wherein said protective atmosphere includes the formation of at a partial vacuum.

17. An apparatus as set forth in Claim 1 wherein said temperature means generally heats said material to said second temperature before transferring said material from said barrel.

18. An apparatus as set forth in Claim 1 wherein said temperature means generally maintains said material at said second temperature while said material is in said shot sleeve.

19. An apparatus as set forth in Claim 1 wherein said temperature means includ s a plurality of heating elements capable of heating said barrel.

20. An apparatus as set forth in Claim 1 wherein said environment control m ans includes plug forming means for forming a solidified plug of said material in said nozzle.

21. An apparatus as set forth in Claim 20 wherein said plug forming means includ s a temperature control mechanism with the nozzle to cool and solidify said material therein after molding of said article.

22. An apparatus as set forth in Claim 1 further comprising a casting die, said casting die including a movable portion and a substantially immovable portion, said movable and immovable portions having surfaces cooperating to define a mold cavity, said mold cavity being oriented with said outlet nozzle to receive said material therefrom.

23. An apparatus as set forth in Claim 22 wherein said casting die includes vacuum means for evacuating said die cavity.

24. An apparatus as set forth in Claim 23 wherein said vacuum means includes a solidified plug of said material in said outlet nozzle.

25. An apparatus as set forth in Claim 1 wherein said shot sleeve is non-horizontally oriented.

26. An apparatus as set forth in Claim 25 wh rein said shot sleeve is oriented such that said inl t thereof is raised relative to said nozzle outlet.

27. An apparatus as set forth in Claim 26 wherein said shot sleeve is inclined within the range of 5° to 45° relative to horizontal.

28. An apparatus as set forth in Claim 26 wherein said shot sleeve is inclined within the range of 15° to 30° relative to horizontal.

29. An apparatus as set forth in Claim 1 further comprising a forging die, said forging die adapted to receive said material from shot sleeve into a die cavity defined therein.

30. An apparatus as set forth in Claim 29 wherein said forging die includes vacuum means for forming at least a partial vacuum in said die cavity.

31. An apparatus as set forth in Claim 29 wherein said vacuum means includes a solidified plug of said material located within said outlet nozzle.

32. An apparatus as set forth in Claim 1 wherein said valve means includes a skirt formed on said ram, said skirt covering said inlet to said shot sleeve during movement of said ram to said fore position.

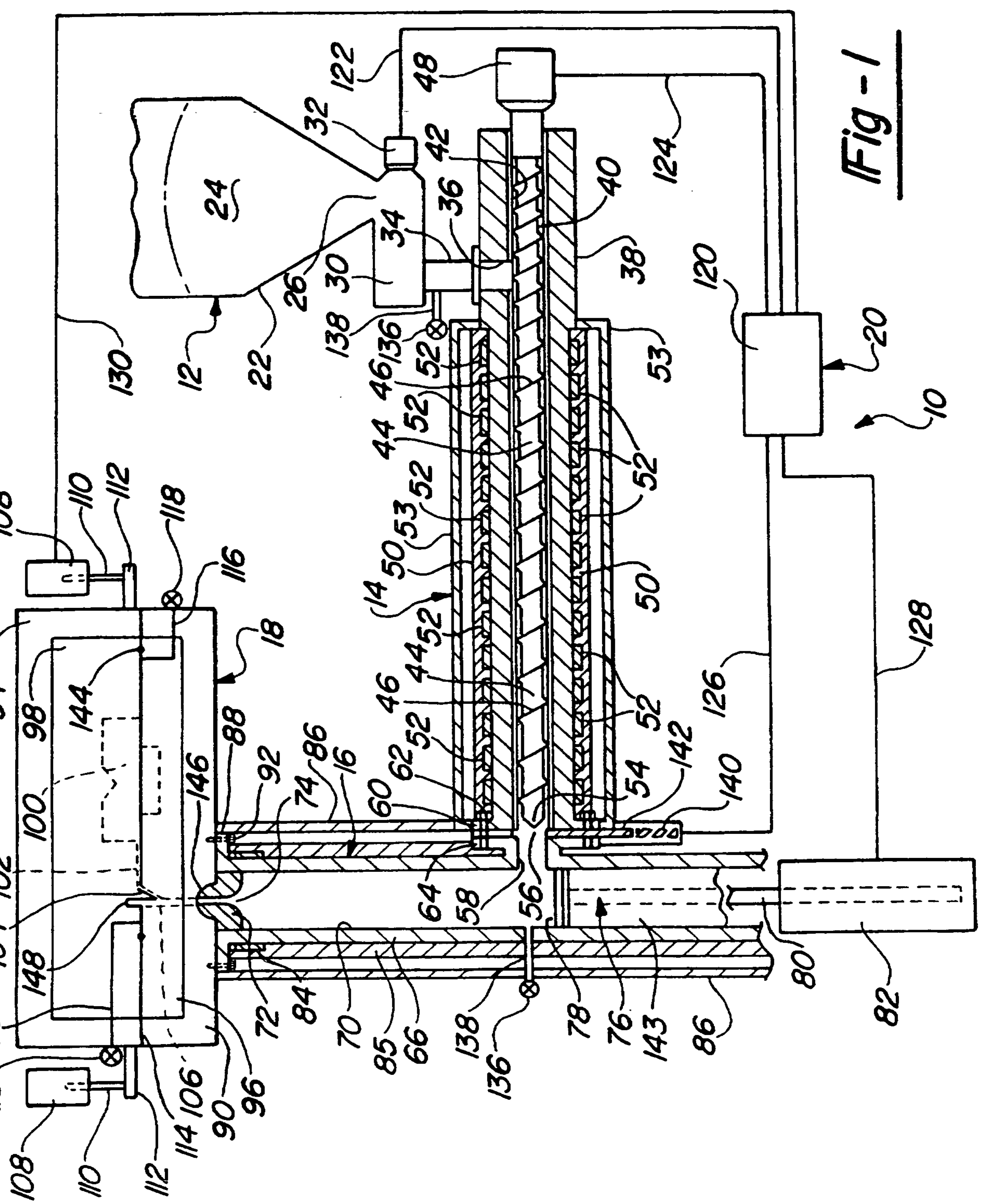

Fig-1

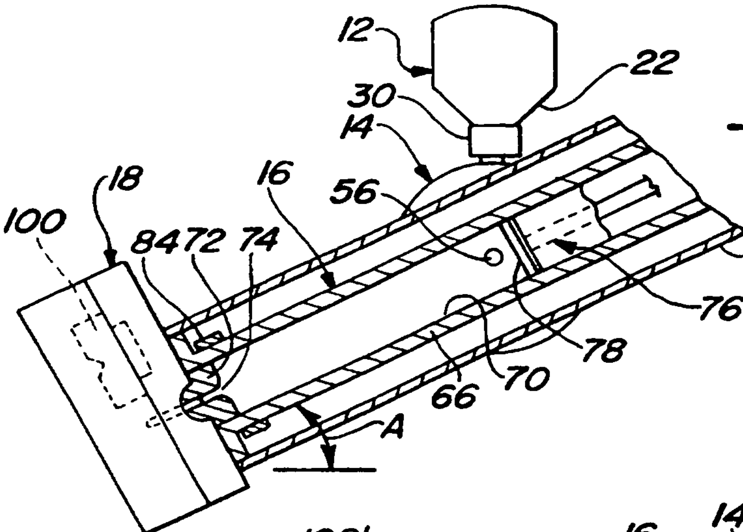

Fig - 2

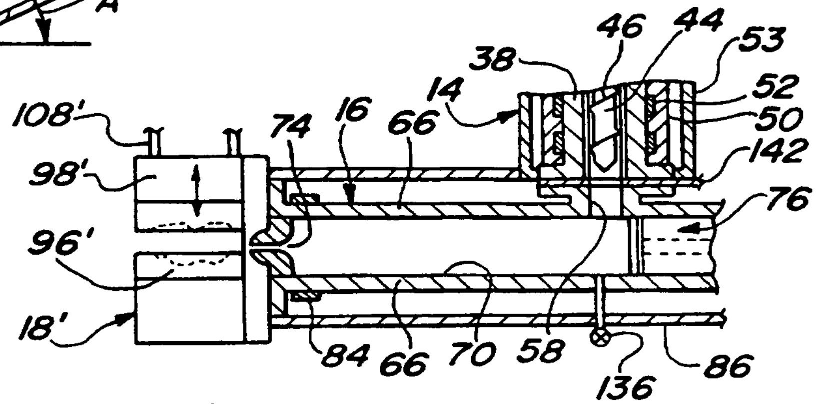

Fig - 3

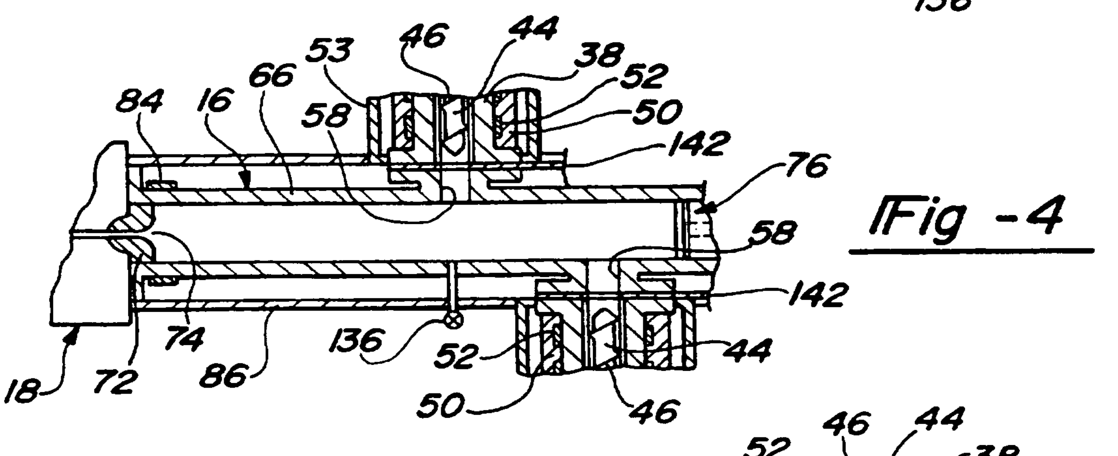

Fig - 4

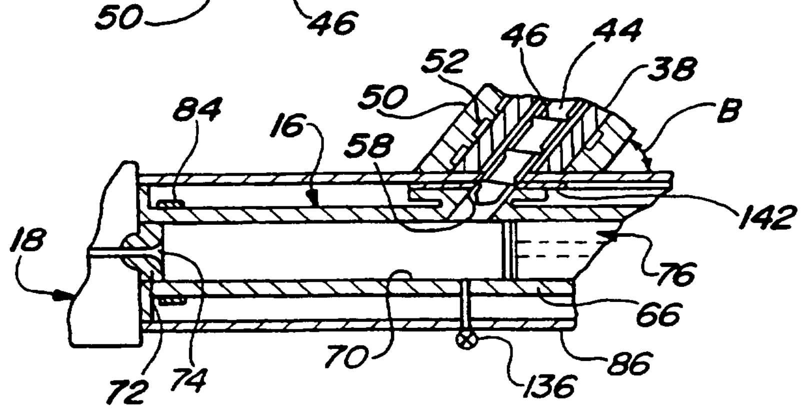

Fig - 5

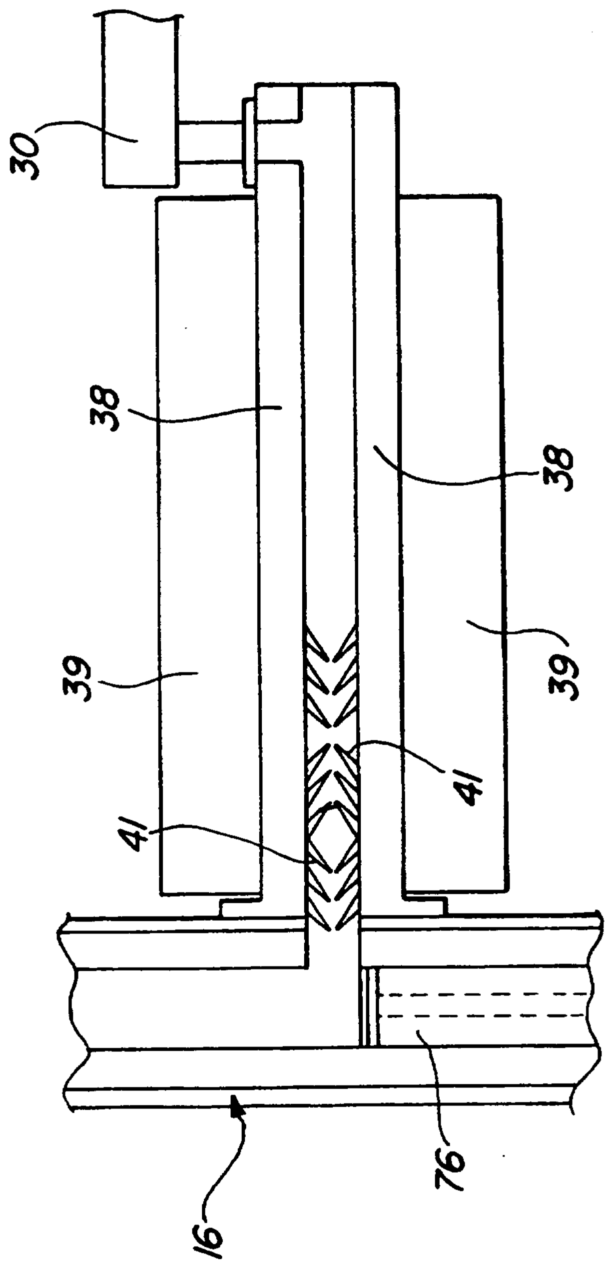

Fig - 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/19763

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B22D 17/00
US CL :164/71.1, 113, 312, 900
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 164/71.1, 113, 312, 900

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,040,589 A (BRADLEY ET AL) 20 AUGUST 1991, COL. 2, LINES 16-30, COL. 4, LINES 57-63, COL. 5, LINES 53-61, FIGURE 1.	1-32
Y	JP 5-285,626 A (KASUYA SAKAMOTO ET AL) 02 NOVEMBER 1993, ABSTRACT, COL. 2, LINES 25-42, COL. 4, LINES 20-26, COL. 5, LINES 44-50, COL. LINES 6, LINES 12-21, FIGURE 1.	1-32
Y	JP 2-274,345 A (EIICHI TAKEUCHI) 08 NOVEMBER 1990, FIGURE 1.	7, 8
Y	US 4,621,676 A (STEWARD) 11 NOVEMBER 1986, FIGURE 1.	7, 8

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"E" earlier document published on or after the international filing date

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 JANUARY 1997	03 FEB 1997

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